



[DOCUMENT] SPECIFICATION

[TITLE OF THE INVENTION]

A Semiconductor Optical Device

[The Scope of the Claims]

5 [Claim 1]

A semiconductor optical device comprising:

10 a first conductivity type semiconductor region,
provided on a surface of GaAs semiconductor, having first
and second semiconductor portions, said first
semiconductor portion having a primary surface, said
primary surface having a first area and second areas, said
first area being provided between said second areas, said
second semiconductor portion having a pair of side surfaces,
said second semiconductor portion being provided on the
15 first area of said first semiconductor portion;

an active layer, provided on said second
semiconductor portion of said first conductivity type
semiconductor region, having a pair of side surfaces;

20 a second conductivity type semiconductor layer,
provided on said active layer, having a pair of side
surfaces; and

a current block semiconductor region for guiding
carriers to said second semiconductor portion, said active
layer, and said second conductivity type semiconductor
25 layer;

wherein the current block semiconductor region is

provided on the second areas of the first semiconductor portion of the first conductivity type semiconductor region, said surfaces of said second semiconductor portion, said side surfaces of said active layer, and said side surfaces of said second conductivity type semiconductor layer;

wherein said active layer is made of III-V compound semiconductor including at least nitrogen (N) as a V group member; and

wherein said active layer is provided so as to generate light having a wavelength of 0.9 micrometers or longer.

[Claim 2]

A semiconductor optical device comprising:

a first conductivity type semiconductor region, provided on a surface of GaAs semiconductor, including a primary surface having a first area and second areas, said first area being provided between said second areas;

a semiconductor ridge including an active layer provided on said first area of said first conductivity type semiconductor region and a second conductivity type semiconductor layer provided on said active layer, said semiconductor ridge having a pair of side surfaces; and

a current block semiconductor region provided on said second areas of said first conductivity type semiconductor region and said side surfaces of said semiconductor ridge, said current block semiconductor region being provided for

guiding carriers to said semiconductor ridge;

wherein said active layer is made of III-V compound semiconductor including at least nitrogen (N) as a V group member; and

5 wherein said active layer is provided to generate light having a wavelength of 0.9 micrometers or longer.
[Claim 3]

 The semiconductor optical device according to claim 2, wherein said first conductivity type semiconductor region is made of semiconductor material enabling said
10 first conductivity type semiconductor region to be a etch stopper resistant to etchant for etching said active layer and said second conductivity type semiconductor layer.
[Claim 4]

15 The semiconductor optical device according to any one of claims 1 to 3, wherein said active layer is made of III-V compound semiconductor including gallium (Ga) as a III group member and

 wherein said III-V compound semiconductor of said
20 active layer includes at least arsenic (As) as a V group member.
[Claim 5]

 The semiconductor optical device according to any one of claims 1 to 4, wherein said active layer is made of at
25 least one of GaInNAs semiconductor; GaNAs semiconductor, GaNAsSb semiconductor, GaNAsP semiconductor, GaNAsSbP

semiconductor, GaInNAsSb semiconductor, GaInNAsP semiconductor and GaInNAsSbP semiconductor.

[Claim 6]

5 The semiconductor optical device according to any one of claims 1 to 5, wherein a refractive index of said second conductivity type semiconductor layer is higher than that of said current block semiconductor region.

[Claim 7]

10 The semiconductor optical device according to any one of claims 1 to 6, further comprising an additional semiconductor layer containing III-V compound semiconductor;

15 wherein said additional semiconductor layer is provided in the following arrangement: between said first conductivity type semiconductor region and said active layer and/or between said second conductivity type semiconductor region and said active layer; and

20 wherein a photoluminescence wavelength of said III-V compound semiconductor is between that of said active layer and that of said first conductivity type semiconductor region.

[Claim 8]

25 The semiconductor optical device according to any one of claims 1 to 6, further comprising a first SCH layer provided between said first conductivity type semiconductor region and said active layer; and

a second SCH layer provided between said second active layer and said second conductivity type semiconductor layer.

[Claim 9]

5 The semiconductor optical device according to claim 8, further comprising an additional semiconductor layer containing III-V compound semiconductor;

 wherein said additional semiconductor layer is provided in the following arrangement: between said first
10 conductivity type semiconductor region and said first SCH layer and/or between said second conductivity type semiconductor region and said second SCH layer; and

 wherein a photoluminescence wavelength of said III-V compound semiconductor is between that of said first SCH
15 layer and that of said first conductivity type semiconductor layer,

 wherein a photoluminescence wavelength of said III-V compound semiconductor is between that of said second
20 SCH layer and that of said second conductivity type semiconductor layer.

[Claim 10]

 The semiconductor optical device according to any one of claims 1 to 9, wherein said current block semiconductor region comprises first and second current block layers;

25 wherein each of said first conductivity type semiconductor region, said second conductivity type

semiconductor layer and said first and second current block layers are made of $(\text{Al}_x\text{Ga}_{1-x})_y\text{In}_{1-y}\text{P}$ semiconductor, where a composition X has a value within the range of zero or greater but not greater than 1.

5 [Claim 11]

The semiconductor optical device according to any one of claims 1 to 9, wherein said current block semiconductor region comprises first and second current block layers;

10 wherein said first conductivity type semiconductor region, said second conductivity type semiconductor layer and said first and second current block layers are made of an $\text{Al}_x\text{Ga}_{1-x}\text{As}$ semiconductor, where a composition X1 has a value within the range of zero or greater but not greater than 1.

15 [Claim 12]

The semiconductor optical device according to claim 8 or 9,

20 wherein said first and second SCH layers are made of one of $\text{Al}_x\text{Ga}_{1-x}\text{As}$ semiconductor ($0 \leq X \leq 1$) and $\text{Ga}_x\text{In}_{1-x}\text{As}_y\text{P}_{1-y}$ semiconductor (about $0.5 \leq X \leq 1$, $0 \leq Y \leq 1$), said $\text{Ga}_x\text{In}_{1-x}\text{As}_y\text{P}_{1-y}$ semiconductor lattice-matching to GaAs semiconductor.

[Claim 13]

25 The semiconductor optical device according to any one of claims 1 to 9 and 12, wherein said current block semiconductor region comprises first and second current

block layers; and

wherein said first and second current block semiconductor layers are made of material not containing aluminum as a III group element.

5 [Claim 14]

The semiconductor optical device according to any one of claims 1 to 9 and 12, wherein said current block semiconductor region comprises first and second current block layers; and

10 wherein said first and second current block semiconductor layers, said first conductivity type semiconductor region and said second conductivity type semiconductor layer are made of material not containing aluminum as a III group element.

15 [Claim 15]

The semiconductor optical device according to any one of claims 1 to 14, wherein said surface of GaAs semiconductor is provided by one of a GaAs semiconductor layer and a gallium arsenide substrate.

20 [Claim 16]

The semiconductor optical device according to any one of claims 1 to 15, wherein said semiconductor optical device is constituted to provide at least one of a semiconductor laser diode, a semiconductor optical amplifier, and an
25 electroabsorption modulator.

[Detail Description of the Invention]

[0001]

[Field of the Invention]

The present invention relates to a semiconductor optical device.

5 [0002]

[Related Background of the Invention]

InGaAsP/InP semiconductor lasers are used as light sources for generating light having a wavelength of 1 micrometer or longer. The structures of the InGaAsP/InP semiconductor lasers can be a ridge type or buried heterostructure type.

10 [0003] Publication 1 (Appl. Phys. Lett. 35(3), 1 August 1979, pp. 232-235) discloses a semiconductor laser having a ridge structure. The semiconductor having a ridge structure comprises an active layer made of an InGaAsP semiconductor. The active layer is provided on the whole surface of a substrate, and is provided between a p-type InP semiconductor layer and an n-type InP semiconductor layer. Carriers, i.e., electrons and holes, are injected into the active layer from the stripe region of the ridge structure. Most of the injected carriers interact with photons in the active layer to generate light, whereas the remaining carriers, i.e., ineffective carriers, fail to interact with photons because the injected carriers spread within the active layer.

25

[0004] Publication 2 (IEEE JOURNAL OF QUANTUM

ELECTRONICS, VOL. QE-17, NO. 2, FEBRUARY 1981, pp. 202-207)
shows a buried heterostructure semiconductor laser. The
buried heterostructure semiconductor laser has an active
layer made of an InGaAsP semiconductor. The active layer
5 is provided between a p-type InP semiconductor layer and
an n-type InP semiconductor layer, and is provided between
current block portions made of an InP semiconductor.
Carriers are injected into the active layer. Due to
heterobarrier between the active layer and the current
10 block portions, the injected carriers are confined within
the active layer.

[0005]

[Non-patent Document 1]

Appl. Phys. Lett. 35(3), 1 August 1979, pp. 232-235

15 [0006]

[Non-patent Document 2]

IEEE JOURNAL OF QUANTUM ELECTRONICS, VOL. QE-17, NO.
2, FEBRUARY 1981, pp. 202-207

[0007]

20 [Problem to be Solved by the Invention]

In order to confine carriers into the active layer,
semiconductor lasers of such types are made of
semiconductor materials that create a barrier height
between the active layer and the semiconductor portion
25 surrounding the active layer. If the active layer is made
of an InGaAsP semiconductor, InP semiconductor can be

combined with InGaAsP semiconductor to provide a heterobarrier therebetween. In this combination of the materials, InP semiconductor attains a barrier height of 2.16×10^{-19} joules (1.35 eV). What is demanded is, however, semiconductor optical devices having temperature characteristics superior to those of semiconductor optical devices made of InGaAsP and InP semiconductors.

[0008] Therefore, it is an object of the present invention to provide a semiconductor optical device having a temperature characteristic superior to those of InGaAsP/InP semiconductor optical devices.

[0009]

[Means for solving the Problem]

According to one aspect of the present invention, a semiconductor optical device comprises: a first conductivity type semiconductor region; a semiconductor ridge; and a current block semiconductor region. The first conductivity type semiconductor region is provided on a surface of GaAs semiconductor and includes a primary surface having a first area and second areas. The first area is provided between the second areas. The semiconductor ridge includes an active layer and a second conductivity type semiconductor layer. The active layer is provided on the first area of the first conductivity type semiconductor region, and the second conductivity type semiconductor layer is provided on the active layer. The

semiconductor ridge has a pair of side surfaces. The current block semiconductor region is provided on the following: the second areas of the first conductivity type semiconductor region; and the side surfaces of the semiconductor ridge. The current block semiconductor region is provided for guiding carriers to the semiconductor ridge. The active layer is made of III-V compound semiconductor including at least nitrogen (N) as a V group member.

[0010]

According to another aspect of the present invention, a semiconductor optical device comprises: a first conductivity type semiconductor region, provided on a surface of GaAs semiconductor, including a primary surface having a first area and second areas, said first area being provided between said second areas; a semiconductor ridge including an active layer provided on said first area of said first conductivity type semiconductor region and a second conductivity type semiconductor layer provided on said active layer, said semiconductor ridge having a pair of side surfaces; and a current block semiconductor region provided on said second areas of said first conductivity type semiconductor region and said side surfaces of said semiconductor ridge, said current block semiconductor region being provided for guiding carriers to said semiconductor ridge. The active layer is made of III-V

compound semiconductor including at least nitrogen (N) as
a V group member.

[0011]

According to these semiconductor optical devices,
5 the active layer is made of III-V compound semiconductor
containing nitrogen as V group element and is provided on
the GaAs substrate. Thus, semiconductor material, lattice
matched to GaAs semiconductor, having a bandgap greater
than InP semiconductor can be used for the material of the
10 first conductive type semiconductor region, the second
conductive type semiconductor region and the current block
semiconductor region. The hetero-barrier heights in the
semiconductor optical devices are greater than that of
semiconductor optical devices made of InGaAsP and InP.

15 [0012]

In the semiconductor optical devices, the photo
luminescence wavelength of the first conductive type
semiconductor region is shorter than that of the active
layer. The photo luminescence wavelength of the second
20 conductive type semiconductor region is shorter than that
of the active layer. The photo luminescence wavelength of
the current blocking semiconductor region is shorter than
that of the active layer. The photo luminescence
wavelength of semiconductor material corresponds to the
25 bandgap of the material.

[0013]

In the semiconductor optical device according to the invention, the active layer is provided to generate light of wavelength greater than or equal to 0.9 micrometers.
[0014]

5 In the semiconductor optical devices, the first conductivity type semiconductor region is made of semiconductor material enabling said first conductivity type semiconductor region to be a etch stopper resistant to etchant for etching said active layer and said second
10 conductivity type semiconductor layer.
[0015]

 In the semiconductor optical devices, said active layer is made of III-V compound semiconductor including gallium (Ga) as a III group member and said III-V compound
15 semiconductor of said active layer includes at least arsenic (As) as a V group member.
[0016]

 In the semiconductor optical devices, a refractive index of said second conductivity type semiconductor layer
20 is higher than that of said current block semiconductor region.
[0017]

 The semiconductor optical devices according to the invention, further comprises an additional semiconductor
25 layer containing III-V compound semiconductor. The additional semiconductor layer is provided in the following

arrangement: between said first conductivity type semiconductor region and said active layer and/or between said second conductivity type semiconductor region and said active layer. A photoluminescence wavelength of said
5 III-V compound semiconductor is between that of said active layer and that of said first conductivity type semiconductor region.

[0018]

According to the relationship of photoluminescence
10 wavelength, the other semiconductor layer prevents spicks or notches from occurring at the heterojunction, and the heterobarrier between the active layer and the first or second conductive type semiconductor layer.

[0019]

15 The semiconductor optical devices according to the present invention further comprise a first SCH layer provided between said first conductivity type semiconductor region and said active layer; and a second SCH layer provided between said second active layer and said
20 second conductivity type semiconductor layer.

[0020]

The first and second SCH layers permit respective confinement of current and light. These SCH layers enhance the light confinement to the active layer and improve the
25 decrease in threshold current, temperature characteristics, and oscillation characteristics.

[0021]

The semiconductor optical devices according to the invention further comprise an additional semiconductor layer containing III-V compound semiconductor. The additional semiconductor layer is provided in the following arrangement: between said first conductivity type semiconductor region and said first SCH layer and/or between said second conductivity type semiconductor region and said second SCH layer. A photoluminescence wavelength of said III-V compound semiconductor is between that of said first SCH layer and that of said first conductivity type semiconductor layer. A photoluminescence wavelength of said III-V compound semiconductor is between that of said second SCH layer and that of said second conductivity type semiconductor layer. According to this relationship of photoluminescence wavelength, the other semiconductor layer prevents spicks or notches from occurring at the heterojunction, and the heterobarrier between the SCH layers and the first and second conductive type semiconductor layers, respectively.

[0022]

In the semiconductor optical device according to the invention, the current block semiconductor region comprises first and second current block layers. Since the current block semiconductor region includes the first and second current block layers the conductive type of which

are opposite to each other, these layers form a p-n junction.

[0023]

5 In the semiconductor optical devices according to the invention, each of said first conductivity type semiconductor region, said second conductivity type semiconductor layer and said first and second current block layers are made of $(\text{Al}_x\text{Ga}_{1-x})_y\text{In}_{1-y}\text{P}$ semiconductor, where a composition X has a value within the range of zero or greater but not greater than 1. This material improves the carrier confinement in the following arrangement: between the active layer and the current block layers; between the active layer and the first and second semiconductor regions.

15 [0024]

In the semiconductor optical device according to the present invention, the current block semiconductor region comprises first and second current block layers. The first conductivity type semiconductor region, said second conductivity type semiconductor layer and said first and second current block layers are made of an $\text{Al}_x\text{Ga}_{1-x}\text{As}$ semiconductor, where a composition X1 has a value within the range of zero or greater but not greater than 1. This material improves the carrier confinement in the following arrangement: between the active layer and the current block layers; between the active layer and the first and second

semiconductor regions.

[0025]

In the e semiconductor optical device according to the invention, the first and second SCH layers are made of one of $\text{Al}_x\text{Ga}_{1-x}\text{As}$ semiconductor ($0 \leq X \leq 1$) and $\text{Ga}_x\text{In}_{1-x}\text{As}_y\text{P}_{1-y}$ semiconductor (about $0.5 \leq X \leq 1$, $0 \leq Y \leq 1$), said $\text{Ga}_x\text{In}_{1-x}\text{As}_y\text{P}_{1-y}$ semiconductor lattice-matching to GaAs semiconductor. These materials allows the photoluminescence wavelengths and refractive indices of the first and second SCH layers

Semiconductor optical devices to be between those of the first and second semiconductor regions and the those of active layer, respectively, thereby achieving the current and light confinements to the active layer.

[0026]

In the semiconductor optical device according to the invention, the current block semiconductor region comprises first and second current block layers. The first and second current block semiconductor layers are made of material not containing aluminum as a III group element.

[0027]

In the semiconductor optical device according to the invention, the current block semiconductor region comprises first and second current block layers. The first and second current block semiconductor layers, said first conductivity type semiconductor region and said second

conductivity type semiconductor layer are made of material not containing aluminum as a III group element.

[0028]

In the semiconductor optical device according to the invention, the surface of GaAs semiconductor is provided by one of a GaAs semiconductor layer and a gallium arsenide substrate.

[0029]

GaAs substrates having large diameters and high quality are available. The GaAs substrates providing GaAs surfaces enhance the productivity and decrease the manufacturing cost. GaAs layers allow GaAs surfaces formed on substrates, such as Silicon substrates, different from GaAs substrates, thereby providing design flexibility, optimization in the structures of semiconductor optical devices, integration of optical and electrical devices.

[0030]

In the semiconductor optical devices according to the present invention, the semiconductor optical device is constituted to provide at least one of a semiconductor laser diode, a semiconductor optical amplifier, and an electroabsorption modulator.

[0031]

In the semiconductor optical devices according to the invention, the active layer is made of at least one of GaInNAs semiconductor; GaNAs semiconductor, GaNAsSb

semiconductor, GaNAsP semiconductor, GaNAsSbP
semiconductor, GaInNAsSb semiconductor, GaInNAsP
semiconductor and GaInNAsSbP semiconductor.

[0032] The above-described object and other objects,
5 features, and advantages of the present invention will
become apparent more easily in the detailed description of
the preferred embodiments of the present invention which
will be described below with reference to the accompanying
drawings.

10 [0033]

[DESCRIPTION OF THE PREFERRED EMBODIMENTS]

The teachings of the present invention will readily
be understood in view of the following detailed
descriptions with reference to the accompanying drawings
15 illustrated by way of example. Referring to the
accompanying drawings, embodiments of the semiconductor
optical device according to the present invention will now
be explained. When possible, parts identical to each other
will be referred to with numerals identical to each other.

20 [0028]

(First Embodiment)

Fig. 1 is a perspective view showing the semiconductor
light-emitting device in accordance with a first embodiment.
XYZ coordinate system S is shown in Fig. 1. Fig. 2(a) is
25 a sectional view taken along the line I-I shown in Fig. 1.
Fig. 2(b) is a diagram showing the band gap taken along the

line II-II of Fig. 2(a). Fig. 2(c) is a diagram showing the refractive index taken along the line II-II of Fig. 2(a). Fig. 2(d) is a diagram showing the band gap taken along the line III-III of Fig. 2(a). Fig. 2(e) is a diagram showing the refractive index taken along the line III-III of Fig. 2(a).

[0035] Referring to Figs. 1 and 2(a), a semiconductor light-emitting device 1, such as a buried heterostructure semiconductor laser device, is illustrated. This semiconductor optical device 1 comprises a first conductivity type semiconductor region 3(a)n active layer 5, a second conductivity type semiconductor layer 7, and a current block semiconductor region 9. The first conductivity type semiconductor region 3 is provided on a surface made of GaAs semiconductor, and has first and second semiconductor portions 3a and 3b. The first semiconductor portion 3(a) has a primary surface having a first region 3c and second regions 3d. The first region 3c is provided between the second regions 3d. The first region 3c extends along a predetermined axis. The second semiconductor portion 3b is provided on the first region 3c of the first semiconductor portion 3a. The second semiconductor portion 3b has a pair of side surfaces 3e. The active layer 5 is provided on the second semiconductor portion 3b of the first conductivity type semiconductor region 3. The active layer 5 has a pair of side faces 5a. The second

conductivity type semiconductor layer 7 is provided on the active layer 5. The second conductivity type semiconductor layer 7 has a pair of side surfaces 7a. The current block semiconductor region 9 is provided on the following: the second region 3d of the first conductivity type semiconductor region 3; each side surface 3e of the second semiconductor portion 3b; each side surface of the active layer 5; and each side surface 7a of the second conductivity type semiconductor layer 7. The active layer 5 is made of a III-V compound semiconductor including at least nitrogen element as a V group member.

[0036] The semiconductor optical device 1 can include the active layer 5 that is provided on a GaAs substrate and is made of a III-V compound semiconductor including at least nitrogen as a V group member. Accordingly, in the semiconductor optical device 1, semiconductor materials lattice-matching to GaAs semiconductor and having a band gap higher than that of InP semiconductors can be used for the first conductivity type semiconductor region 3, the second conductivity type semiconductor layer 7, and the current block semiconductor region 9. The heterobarrier associated with the active layer in the semiconductor optical device can be made higher than that in InGaAsP/InP semiconductor optical devices.

[0037] Since the semiconductor optical device 1 has a buried heterostructure, it is superior to semiconductor

lasers of a ridge structure in the confinement of carriers. Consequently, the semiconductor laser with a buried heterostructure lowers the ineffective current and enhances the interaction between carriers and photons, thereby attaining improvement in differential efficiency and reduction in the threshold current.

[0038] The first conductivity type semiconductor region 3 is made of by a III-V compound semiconductor, whereas this III-V compound semiconductor has a photoluminescence wavelength lower than that of the active layer 5. The second conductivity type semiconductor layer 7 is made of a III-V compound semiconductor, whereas this III-V compound semiconductor has a photoluminescence wavelength lower than that of the active layer 5. Here, the value of the photoluminescence wavelength is equal to the wavelength value corresponding to the band gap energy of the material. As shown in the band gap diagram of Fig. 2(b), the first conductivity type semiconductor region 3(a)nd the second conductivity type semiconductor layer 7 work so as to confine carriers into the active layer 5. As a result, the first conductivity type semiconductor region 3 can work as a cladding layer of the first conductivity type, whereas the second conductivity type semiconductor layer 7 can work as a second conductivity type cladding layer. After carriers is injected into the active layer 5 from the first conductivity type semiconductor region

3(a)nd the second conductivity type semiconductor layer 7, the carriers is confined into the active layer 5 and generates light.

[0039] As shown in Fig. 2(b), in an InP/InGaAsP semiconductor light-emitting device, the cladding layers of the semiconductor light-emitting device 1 exhibit a band gap value ΔE_0 higher than the band gap value ΔE_{InP} of a cladding layer made of InP semiconductor, so that the semiconductor light-emitting device 1 is superior to the InP/InGaAsP semiconductor light-emitting device in terms of the carrier confinement in the y direction.

[0040] The current block semiconductor region 9 is made of a III-V compound semiconductor, whereas this III-V compound semiconductor exhibits a photoluminescence wavelength value lower than that of the active layer 5. As shown in the band gap diagram of Fig. 2(d), the current block semiconductor region 9 works as a current block semiconductor layer. As shown in Fig. 2(d), the current block semiconductor layer in the semiconductor light-emitting device 1 exhibits a band gap value ΔE_B higher than the band gap value ΔE_{InP} of the cladding layer made of InP semiconductor in the InP/InGaAsP semiconductor light-emitting device, whereby the semiconductor light-emitting device 1 is superior to the InP/InGaAsP semiconductor light-emitting device in terms of the carrier confinement in the x direction.

[0041] As shown in the refractive index distribution of Fig. 2(c), the first conductivity type semiconductor region 3 exhibits a refractive index lower than that of the active layer 5. The second conductivity type semiconductor layer 7 exhibits a refractive index lower than that of the active layer 5. Therefore, the first conductivity type semiconductor region 3 and the second conductivity type semiconductor layer 7 acts to guide the light generated in the active layer 5 into the active layer 5 in the Y direction. As a result, the semiconductor region 3 works as an optical cladding layer of the first conductivity type, and the semiconductor layer 7 works as an optical cladding layer of the second conductivity type.

[0042] The current block semiconductor region 9 is made of III-V compound semiconductor, which exhibits a refractive index lower than that of the active layer 5. As a result, the current block semiconductor region 9 serves to guide light generated in the active layer 5 into the active layer 5, and acts as an optical cladding layer.

[0043] The semiconductor optical device 1 further comprises a semiconductor substrate 11. For example, a GaAs semiconductor substrate can be used as the semiconductor substrate 11. The surface of GaAs semiconductor on which the first conductivity type semiconductor region 3 is formed is provided by a GaAs semiconductor substrate. The first conductivity type

semiconductor region 3 is provided on a primary surface 11a of the semiconductor substrate 11. The first conductivity type semiconductor region 3 includes the first portion 3(a) provided on the primary surface 11a of the semiconductor substrate 11, and the second portion 3b provided on the first portion 3(a). The second portion 3b of the first conductivity type semiconductor region 3 is formed into a ridge, and is provided between the current block semiconductor region 9 which is provided on the first portion 3(a). The active layer 5 and the second conductivity type semiconductor layer 7 are formed into a ridge, and are provided between the current block semiconductor region 9. The active layer 5 is provided between the second portion 3b of the first conductivity type semiconductor region 3 and the second conductivity type semiconductor layer 7. The second portion 3b of the first conductivity type semiconductor region 3, the active layer 5, and the second conductivity type semiconductor layer 7 constitute a semiconductor ridge 13. The semiconductor ridge 13 extends along the predetermined axis. In the semiconductor ridge 13, carriers are injected into the active layer 5 from the second conductivity type semiconductor layer 7 and the second portion 3b of the first conductivity type semiconductor region 3.

[0044] The semiconductor optical device 1 further comprises a second conductivity type semiconductor layer

15 provided on the current block semiconductor region 9 and the semiconductor ridge 13. The second conductivity type semiconductor layer 15 exhibits a photoluminescence wavelength value equal to or lower than that of the second conductivity type semiconductor layer 7, and lower than that of the active layer 5. The second conductivity type semiconductor layer 15 exhibits a refractive index equal to or lower than that of the second conductivity type semiconductor layer 7, and lower than that of the active layer 5. Therefore, the second conductivity type semiconductor layer 15 acts to confine the generated light and injected carriers into the active layer 5. As a result, the semiconductor layer 15 works as an optical cladding layer of the second conductive type.

[0045] The semiconductor optical device 1 having such a refractive index structure and band gap structure can enhance the carrier confinement in lateral transverse and longitudinal directions, thereby lowering the threshold current, increasing the slope efficiency, and improving the temperature characteristic.

[0046] The semiconductor device 1 further comprises a second conductivity type semiconductor layer 17, and electrodes 21 and 23. The second conductivity type semiconductor layer 17 is provided on the second conductivity type semiconductor layer 15. The electrode 21 is provided on the second conductivity type

semiconductor layer 17. The electrode 21 extends in the same direction as with the semiconductor ridge 13. The electrode 23 is provided on the rear surface 11b of the substrate 11. The band gap of second conductivity type semiconductor layer 17 is smaller than that of the second conductivity type semiconductor layer 15. This makes it easier to realize ohmic contact between the second electrode 21 and the second conductivity type semiconductor layer 17. The second conductivity type semiconductor layer 17 acts as a contact layer.

[0047] In the semiconductor optical device 1, each current block semiconductor region 9 may have a first current block layer 9a and a second current block layer 9b. The conductivity type of the first current block layer 9a is different from that of the second current block layer 9b. Since the current block semiconductor region 9 includes these semiconductor layers that form a p-n junction, the p-n junction between the first current block layer 9a and the second current block layer 9b serves to block currents. The first and second current block layers 9a and 9b may be made of semiconductor materials of the second and first conductivity type, respectively.

[0048] In the semiconductor optical device 1 shown in Figs. 1 and 2(a), the first current block layer 9a is provided between the second current block layer 9b of the first conductivity type semiconductor and the first

conductivity type semiconductor region 3, whereas the second current block layer 9b is provided between the first current block layer 9a of the second conductivity type semiconductor and the second conductivity type semiconductor layer 15. Hence, the second conductivity type semiconductor layer 15, first conductivity type semiconductor region 3(a) and current block semiconductor region 9 construct a p-n-p-n or n-p-n-p structure.

[0049] In a first example of the semiconductor light-emitting device 1,

the first conductivity type semiconductor region 3: n-type AlGaInP or GaInP;

the active layer 5: undoped (hereinafter referred to as "un") GaInNAs, un-GaNAs, un-GaNAsSb, un-GaNAsP, un-GaNAsSbP, un-GaInNAsSb, un-GaInNAsP, and/or un-GaInNAsSbP;

the second conductivity type semiconductor layer 7: p-type AlGaInP semiconductor and/or GaInP semiconductor;

the second conductivity type semiconductor layer 15: p-type AlGaInP or GaInP;

the first current block semiconductor layer 9a: p-type AlGaInP semiconductor, p-type AlGaAs semiconductor, p-type GaAs semiconductor, or p-type GaInP semiconductor;

the second current block semiconductor layer 9b: n-type AlGaInP semiconductor, n-type GaInP semiconductor, n-type AlGaAs semiconductor, and/or n-type GaAs

semiconductor;

the substrate 11: n-type heavily doped GaAs substrate; and

the contact layer 17: p-type GaAs semiconductor. In
 5 the semiconductor optical device 1, the first conductivity
 type semiconductor region 3(a)nd the second conductivity
 type semiconductor layer 7 may be made by an $(\text{Al}_x\text{Ga}_{1-x})_y\text{In}_{1-y}\text{P}$
 semiconductor lattice-matching to GaAs semiconductor,
 whereas each of the first and second current block layers
 10 9a and 9b may be made of an $\text{Al}_x\text{Ga}_{1-x}\text{P}$ semiconductor or an
 $(\text{Al}_x\text{Ga}_{1-x})_y\text{In}_{1-y}\text{P}$ semiconductor that lattice-matches to GaAs
 semiconductor. In these semiconductor crystals, a
 composition "X" has a value within the range of zero or
 greater but not greater than 1. Using these semiconductor
 15 materials can improve the carrier confinement at the
 following interfaces: the active layer 5 and the current
 block semiconductor regions 9; the active layer 5 and the
 first conductivity type semiconductor region 3(a)nd the
 active layer 5 and the second conductivity type
 20 semiconductor layer 7.

[0050] In a second example of the semiconductor
 light-emitting device 1,

the first conductivity type semiconductor region 3:
 n-type AlGaAs semiconductor and/or GaAs semiconductor;

25 the active layer 5: un-GaInNAs, un-GaNAs, un-GaNAsSb,
 un-GaNAsP, un-GaNAsSbP, un-GaInNAsSb, un-GaInNAsP and/or

un-GaInNAsSbP;

the second conductivity type semiconductor layer 7:
p-type AlGaAs semiconductor and/or GaAs semiconductor;

the second conductivity type semiconductor layer 15:
5 p-type AlGaAs semiconductor and/or GaAs semiconductor;

the first current block semiconductor layer 9a:
p-type AlGaInP semiconductor, p-type AlGaAs semiconductor,
p-type GaAs semiconductor, and/or p-type GaInP
semiconductor;

10 the second current block semiconductor layer 9b:
n-type AlGaInP semiconductor, n-type GaInP semiconductor,
n-type AlGaAs semiconductor, and/or n-type GaAs
semiconductor;

the substrate 11: heavily-doped n-type GaAs
15 substrate; and

the contact layer 17: p-type GaAs semiconductor. In
the semiconductor optical device 1 of this example, the
first conductivity type semiconductor region 3(a) and the
second conductivity type semiconductor layer 7 may be made
20 of an $\text{Al}_x\text{Ga}_{1-x}\text{As}$ semiconductor, whereas each of the first
and second current block layers 9a and 9b may be made of
an $\text{Al}_x\text{Ga}_{1-x}\text{As}$ semiconductor or an $(\text{Al}_x\text{Ga}_{1-x})_y\text{In}_{1-y}\text{P}$
semiconductor that lattice-matches to GaAs semiconductor.
In these semiconductor crystals, parameter "X" has a value
25 within the range of zero or greater zero but not greater
than 1. Using this semiconductor material can improve the

carrier confinement at the following interfaces: the active layer 5 and the current block semiconductor regions 9; the active layer 5 and the first conductivity type semiconductor region 3(a) and the active layer 5 and the second conductivity type semiconductor layer 7.

[0051] In the semiconductor optical device 1 containing the above-mentioned semiconductor materials, the active layer 5 is provided so as to generate light having a wavelength of 0.9 micrometers or longer.

[0052] In Fig. 2(b), InP semiconductor has band gap, ΔE_{InP} , and the semiconductor material of the cladding layers has band gap ΔE_0 . As can be seen from Fig. 2(b), band gap ΔE_0 is greater than band gap ΔE_{InP} . That is, the band gap difference of the hetero-junction between the active layer 5 (which is made of one of GaInNAs, GaNAs, GaNAsSb, GaNAsP, GaNAsSbP, GaInNAsSb, GaInNAsP, and GaInNAsSbP semiconductors) and p- and n-type cladding layers (which are made of p-type AlGaInP, n-type AlGaInP, p-type AlGaAs, or n-type AlGaAs semiconductor) can be made greater than the band gap difference between InP semiconductor and GaInAsP semiconductor, where InP semiconductor has a band gap energy of 2.16×10^{-19} joules (1.35 eV). This explanation similarly applies to the active layer 5 and the current block semiconductor regions 9 shown in Fig. 2(d).

[0053] Fig. 3(a) is a sectional view showing a modified example of the semiconductor optical device in accordance

with the first embodiment. Fig. 3(b) is a diagram showing the band gap taken along the line IV-IV of Fig. 3(a). Fig. 3(c) is a diagram showing the refractive index taken along the line IV-IV of Fig. 3(a). The semiconductor optical device 1a may further comprise a first SCH layer 25 and a second SCH layer 27. The first SCH layer 25 is provided between the first conductivity type semiconductor region 3(a) and the active layer 5. The second SCH layer 27 is provided between the active layer 5 and the second conductivity type semiconductor layer 7. The first and second SCH layers 25 and 27 are provided between the current block regions 9. The second portion 3b of the first conductivity type semiconductor region 3, the active layer 5, the second conductivity type semiconductor layer 7, and the first and second SCH layers 25 and 27 constitute a semiconductor ridge 13a.

[0054] The photoluminescence wavelength of the first SCH layer 25 is between that of the active layer 5 and that of the first conductivity type semiconductor region 3. The second SCH layer 27 exhibits a photoluminescence wavelength having a value between that of the active layer 5 and that of the second conductivity type semiconductor layer 7. Carriers are injected into the active layer 5 by way of the first and second SCH layers 25 and 27 from the second conductivity type semiconductor layer 7 and the second portion 3b of the first conductivity type semiconductor

region 3. In the semiconductor optical device 1a, as shown in Fig. 3(b), the first and second SCH layers 25 and 27 act to confine the injected carriers into the active layer 5.

[0055] The refractive index of the first SCH layer 25

is between that of the active layer 5 and that of the first conductivity type semiconductor region 3. The refractive

index of the second SCH layer 27 is between that of the active layer 5 and that of the second conductivity type

semiconductor layer 7. As shown in Fig. 3(c), the first

semiconductor region 3(a) and the second conductivity type semiconductor layer 7 function to confine light generated in the active layer 5 into the active layer 5 and the first and second SCH layers 25 and 27.

[0056] The first and second SCH semiconductor layers

25 and 27 make it possible to confine carriers and light separately. These SCH layers function to enhance the

confinement of light into the active layer 5, thereby providing the semiconductor light-emitting device 1 with

improvement in oscillation characteristics, such as a reduction in the threshold current, and the temperature

characteristic.

[0057] Each of the first and second SCH layers may be

made of an $\text{Al}_x\text{Ga}_{1-x}\text{As}$ semiconductor ($0 \leq x \leq 1$) or a $\text{Ga}_x\text{In}_{1-x}\text{As}_y\text{P}_{1-y}$ semiconductor (about $0.5 \leq x \leq 1$, $0 \leq y \leq 1$)

that lattice-matches to GaAs semiconductor. First and second examples of the semiconductor light-emitting device

1a are presented as follows:

the first and second SCH semiconductor layers 25, 27:
un- $\text{Al}_x\text{Ga}_{1-x}\text{As}$ ($0 \leq X \leq 1$), un-GaAs, and/or a $\text{Ga}_x\text{In}_{1-x}\text{As}_y\text{P}_{1-y}$
semiconductor (about $0.5 \leq X \leq 1$, $0 \leq Y \leq 1$) lattice-matching
5 to GaAs semiconductor. In the above example, GaInAsP
semiconductor is provided so as to lattice-match to GaAs
semiconductor. According to the above materials, the
refractive indices of the first and second SCH
semiconductor layers 25 and 27 fall within values between
10 those of the first conductivity type semiconductor region
3 and second conductivity type semiconductor layer 7 and
index of the active layer 5, and the photoluminescence
wavelengths of the first and second SCH semiconductor
layers 25 and 27 fall within values between those of the
15 first conductivity type semiconductor region 3 and second
conductivity type semiconductor layer 7 and index of the
active layer 5. Accordingly, light and carriers can be
confined into the active layer 5.

[0058] Fig. 4(a) is a sectional view showing a modified
20 example of the semiconductor optical device in accordance
with the first embodiment. Fig. 4(b) is a diagram showing
the band gap taken along the line V-V of Fig. 4(a). Fig.
4(c) is a diagram showing the band gap of another
semiconductor optical device taken along a line
25 corresponding to line V-V of Fig. 4(a). The semiconductor
optical device 1b may further comprise an additional

semiconductor layer 29 including a III-V compound semiconductor. The additional semiconductor layer 29 is provided in the following arrangements: between the first conductivity type semiconductor region 3(a) and the active layer 5; and between the second conductivity type semiconductor layer 7 and the active layer 5. If the additional semiconductor layer 29 is provided between the second conductivity type semiconductor layer 7 and the active layer 5 in the semiconductor optical device 1b, the III-V compound semiconductor of the additional semiconductor layer 29 exhibits a photoluminescence wavelength value between that of the active layer 5 and that of the second conductivity type semiconductor layer 7 as shown in Fig. 4(b). If the additional semiconductor layer 29 is provided between the first conductivity type semiconductor region 3(a) and the active layer 5, the III-V compound semiconductor of the additional semiconductor layer 29 exhibits a photoluminescence wavelength value between that of the active layer 5 and that of the first conductivity type semiconductor region 3. The second portion 3b of the first conductivity type semiconductor region 3, the active layer 5, the second conductivity type semiconductor layer 7, and the additional semiconductor layer 29 constitute a semiconductor ridge 13b.

[0059] According to the relationship of photoluminescence wavelengths as above, the additional

semiconductor layer 29 lower spikes and notches at a heterojunction interfaces, thereby alleviating the heterobarrier in the following arrangements: the active layer 5 and the first conductivity type semiconductor region 3; the active layer 5 and the second conductivity type semiconductor layer 7.

[0060] In Fig. 4(a), the semiconductor light-emitting device 1b comprises the additional semiconductor layer 29 provided between the second conductivity type semiconductor layer 7 and the active layer 5, but it may be provided between the first conductivity type semiconductor region 3 and the active layer 5 as shown in Fig. 4(c). Both additional semiconductor layers may be provided on both sides of the active layer 5.

[0061] In the first and second examples in the semiconductor light-emitting device 1b, the semiconductor layer 29 is made of p-type AlGaAs, p-type AlGaInP, p-type GaInP, and/or p-type GaInAsP.

[0062] Fig. 5 is a sectional view showing a modified example of the semiconductor optical device in accordance with the first embodiment. The semiconductor optical device 1c shown in Fig. 5 may comprise SCH layers 25 and 27 and an additional semiconductor layer 31 including a III-V compound semiconductor. The additional semiconductor layer 31 is provided between the second conductivity type semiconductor layer 7 and the second SCH

layer 27. If the additional semiconductor layer 31 is provided between the second conductivity type semiconductor layer 7 and the second SCH layer 27 as in the semiconductor optical device 1c, the III-V compound semiconductor of the additional semiconductor layer 31 exhibits a photoluminescence wavelength value between that of the second SCH layer 27 and that of the second conductivity type semiconductor layer 7. If the additional semiconductor layer 31 is provided between the first conductivity type semiconductor region 3(a) and the first SCH layer 25, the III-V compound semiconductor of the additional semiconductor layer 31 has a photoluminescence wavelength value between that of the first SCH layer 25 and that of the first conductivity type semiconductor region 3. The second portion 3b of the first conductivity type semiconductor region 3, the active layer 5, the second conductivity type semiconductor layer 7, the first and second SCH layers 25 and 27, and the additional semiconductor layer 31 constitute a semiconductor ridge 13c.

[0063] The additional layer 31 may be provided in at least one of the interfaces in the following arrangements: the first conductivity type semiconductor region 3(a) and the first SCH layer 25; and the second conductivity type semiconductor layer 7 and the second SCH layer 27.

[0064] According to the relationship of

photoluminescence wavelengths as above, the additional semiconductor layer 31 lowers spikes and notches at heterojunction interfaces, thereby alleviating the heterobarrier in the following arrangements: the first SCH layer 25 and the first conductivity type semiconductor region 3; the second SCH layer 27 and the second conductivity type semiconductor layer 7.

[0065] In the first and second examples of the semiconductor light-emitting device 1c, the semiconductor layer 31 is made of p-type AlGaAs, p-type AlGaInP, p-type GaInP, and/or p-type GaInAsP.

[0066]

(Second Embodiment)

Fig. 6 is a perspective view showing the semiconductor light-emitting device of a second embodiment. XYZ coordinate system S is shown in Fig. 6. Fig. 7(a) is a sectional view showing the semiconductor light-emitting device taken along the line VI-VI shown in Fig. 6. Fig. 7(b) is a diagram showing the band gap taken along the line VII-VII of Fig. 7(a). Fig. 7(c) is a diagram showing the refractive index taken along the line VII-VII of Fig. 7(a). Fig. 7(d) is a diagram showing the band gap taken along the line VIII-VIII of Fig. 7(a). Fig. 7(e) is a diagram showing the refractive index taken along the line VIII-VIII of Fig. 7(a). Referring to Figs. 6 and 7(a), a semiconductor light-emitting device 51 such as a buried heterostructure

semiconductor laser device is shown.

[0067] This semiconductor optical device 51 comprises a first conductivity type semiconductor region 53(a)n active layer 55, a second conductivity type semiconductor layer 57, and a current block semiconductor region 59. The first conductivity type semiconductor region 53 is provided on a surface of GaAs semiconductor. The first conductivity type semiconductor region 53 comprises a primary surface having a first region 53a and second regions 53b provided on both sides of the first region 53(a). The first region 53(a) extends along a predetermined axis. The active layer 55 is provided on the first region 53(a). The active layer 55 has a pair of side surfaces 55a. The second conductivity type semiconductor layer 57 is provided on the active layer 55. The second conductivity type semiconductor layer 57 has a pair of side surfaces 57a. The current block semiconductor region 59 is provided on the following regions: the second regions 53b of the first conductivity type semiconductor region 53; each side surface 55a of the active layer 55; and each side surface 57a of the second conductivity type semiconductor layer 57. The active layer 55 is provided by III-V compound semiconductor including at least nitrogen element as a V group member.

[0068] In the semiconductor optical device 51, the active layer 55 made of a III-V compound semiconductor containing at least nitrogen element as a V group member

can be provided on a GaAs substrate, whereby the first conductivity type semiconductor region 53, the second conductivity type semiconductor layer 57, and the current block semiconductor regions 59a can be made of semiconductor material lattice-matching to GaAs semiconductor and having a band gap higher than that of InP semiconductors. The heterobarrier associated with the active layer in such a semiconductor optical device can be made higher than that in InGaAsP/InP semiconductor optical devices.

[0069] The first conductivity type semiconductor region 53 is made of III-V compound semiconductor, and this III-V compound semiconductor exhibits a photoluminescence wavelength value lower than that of the active layer 55. The second conductivity type semiconductor layer 57 is made of III-V compound semiconductor, and this III-V compound semiconductor exhibits a photoluminescence wavelength value lower than that of the active layer 55. A photoluminescence wavelength value of the semiconductor material is equal to a wavelength value corresponding to its band gap energy. As shown in the band gap diagram of Fig. 7(b), the first conductivity type semiconductor region 53 and the second conductivity type semiconductor layer 57 function to confine carriers into the active layer 55. Accordingly, the first conductivity type semiconductor region 53 functions as a first conductivity type cladding

layer, whereas the second conductivity type semiconductor layer 57 functions as a second conductivity type cladding layer. The active layer 55 generates light in response to carriers confined therein and injected from the first conductivity type semiconductor region 53(a) and the second conductivity type semiconductor layer 57. As shown in Fig. 7(b), the semiconductor light-emitting device 51 has a cladding layer with a band gap value ΔE_0 higher than the band gap value ΔE_{InP} of a cladding layer made of InP semiconductor in an InP/InGaAsP semiconductor light-emitting device. Thus, the semiconductor light-emitting device 51 is superior to the InP/InGaAsP semiconductor light-emitting device in terms of the carrier confinement in the Y direction.

[0070] The current block semiconductor region 59 is made of a III-V compound semiconductor, whereas this III-V compound semiconductor exhibits a photoluminescence wavelength value lower than that of the active layer 55. As a result, as shown in the band gap diagram of Fig. 7(d), the current block semiconductor region 59 function as a semiconductor layer for blocking current. As shown in Fig. 7(d), the semiconductor light-emitting device 51 has a current block semiconductor layer exhibiting a band gap value ΔE_B higher than the band gap value ΔE_{InP} of the InP current block semiconductor layer in the InP/InGaAsP semiconductor light-emitting device. Thus, the

semiconductor light-emitting device 51 is superior to the InP/InGaAsP semiconductor light-emitting device in terms of the carrier confinement in the X direction.

[0071] As shown in the refractive index distribution of Fig. 7(c), the first conductivity type semiconductor region 53 exhibits a refractive index lower than that of the active layer 55. The second conductivity type semiconductor layer 57 exhibits a refractive index lower than that of the active layer 55. Accordingly, the first conductivity type semiconductor region 53 and the second conductivity type semiconductor layer 57 function to confine light generated in the active layer 55 into the active layer 55. Consequently, the first conductivity type semiconductor region 53 works as an optical cladding layer, and the second conductivity type semiconductor layer 57 acts as an optical cladding layer.

[0072] The current block semiconductor region 59 is made of a III-V compound semiconductor, whereas this III-V compound semiconductor exhibits a refractive index lower than that of the active layer 55. Accordingly, the current block semiconductor region 59 functions to confine light generated in the active layer 55 into the active layer 55, and acts as an optical cladding layer.

[0073] The semiconductor optical device 51 further comprises a semiconductor substrate 61. A GaAs semiconductor substrate is shown as an example of the

semiconductor substrate 61. A GaAs semiconductor substrate can realize the surface of GaAs semiconductor on which the first conductivity type semiconductor region 53 is formed. The first conductivity type semiconductor region 53 is provided on a primary surface 61a of the semiconductor substrate 61. The active layer 55 and the second conductivity type semiconductor layer 57 are provided between the current block semiconductor regions 59, and are formed into a ridge. The active layer 55 is provided between the second conductivity type semiconductor layer 57 and the first portion 53(a) of the first conductivity type semiconductor region 53. The active layer 55 and the second conductivity type semiconductor layer 57 constitute a semiconductor ridge 63. The semiconductor ridge 63 extends along a predetermined axis. In the semiconductor ridge 63, carriers are injected into the active layer 55 from the second conductivity type semiconductor layer 57 and the first portion 53(a) of the first conductivity type semiconductor region 53.

[0074] The semiconductor optical device 51 further comprises a second conductivity type semiconductor layer 65 provided on the current block semiconductor region 59 and the semiconductor ridge 63. The second conductivity type semiconductor layer 65 exhibits a photoluminescence wavelength value equal to or lower than that of the second conductivity type semiconductor layer 57, and lower than

that of the active layer 55. The second conductivity type semiconductor layer 65 exhibits a refractive index equal to or lower than that of the second conductivity type semiconductor layer 57, and lower than that of the active layer 55. Accordingly, the second conductivity type semiconductor layer 65 confines the generated light and injected carriers into the active layer 55. The second conductivity type semiconductor layer 65 works as a cladding layer.

[0075] The semiconductor device 51 further comprises a second conductivity type semiconductor layer 67, and electrodes 71 and 73. The second conductivity type semiconductor layer 67 is provided on the second conductivity type semiconductor layer 65. The electrode 71 is provided on the second conductivity type semiconductor layer 67. The electrode 71 extends in the direction in which the semiconductor ridge 63 extends. The electrode 73 is provided on the rear side 61b of the substrate 61. The second conductivity type semiconductor layer 67 has a band gap smaller than that of the second conductivity type semiconductor layer 65. This makes it easier to form ohmic contact between the second electrode 71 and the second conductivity type semiconductor layer 67. Consequently, the second conductivity type semiconductor layer 67 works as a contact layer.

[0076] In the semiconductor optical device 51, the

current block semiconductor region 59 may have a first current block layer 59a and a second current block layer 59b. The conductivity type of the first current block layer 59a is different from that of the second current block layer 59b. The current block semiconductor region 59 includes a p-n junction constituted by the first and second current block layers 59a and 59b. This p-n junction can block currents. The first and second current block layers 59a and 59b may be made of semiconductor materials of the second and first conductivity type, respectively.

[0077] In the semiconductor optical device 51, the first current block layer 59a is provided between the first conductivity type semiconductor region 53(a) and the second current block layer 59b of a first conductivity type semiconductor, whereas the second current block layer 59b is provided between the second conductivity type semiconductor layer 65 and the first current block layer 59a of a second conductivity type semiconductor. Hence, the second conductivity type semiconductor layer 65, the first conductivity type semiconductor region 53(a) and the current block semiconductor region 59 constructs a p-n-p-n or n-p-n-p structure.

[0078] In a first example of the semiconductor light-emitting device 51:

the first conductivity type semiconductor region 53: n-type AlGaInP semiconductor and/or GaInP semiconductor;

the active layer 55: un-GaInNAs semiconductor,
 un-GaNAs semiconductor, un-GaNAsSb semiconductor,
 un-GaNAsP semiconductor, un-GaNAsSbP semiconductor,
 un-GaInNAsSb semiconductor, un-GaInNAsP semiconductor,
 5 and/or un-GaInNAsSbP semiconductor;

the second conductivity type semiconductor layer 57:
 p-type AlGaInP semiconductor and/or GaInP semiconductor;

the second conductivity type semiconductor layer 65:
 p-type AlGaInP semiconductor and/or GaInP semiconductor;

10 the first current block semiconductor layer 59a:
 p-type AlGaInP semiconductor, p-type AlGaAs semiconductor,
 p-type GaAs semiconductor, and/or p-type GaInP
 semiconductor;

the second current block semiconductor layer 59b:
 15 n-type AlGaInP semiconductor, n-type GaInP semiconductor,
 n-type AlGaAs semiconductor, and/or n-type GaAs
 semiconductor;

the substrate 61: heavily-doped n-type GaAs
 substrate; and

20 the contact layer 67: p-type GaAs semiconductor. In
 the semiconductor optical device 51, the first conductivity
 type semiconductor region 53(a) and the second conductivity
 type semiconductor layer 57 may be made of an $(\text{Al}_x\text{Ga}_{1-x})_y\text{In}_{1-y}\text{P}$
 semiconductor that lattice-matches to GaAs semiconductor,
 25 whereas each of the first and second current block layers
 59a and 59b may be made of an $\text{Al}_x\text{Ga}_{1-x}$ semiconductor and/or

an $(\text{Al}_x\text{Ga}_{1-x})_y\text{In}_{1-y}\text{P}$ semiconductor that lattice-matches to GaAs semiconductor. In these semiconductor crystals, composition "X" has a value within the range of zero or greater but not greater than 1. Using this semiconductor material can improve the carrier confinement in the following arrangements: between the active layer 55 and the current block semiconductor region 59; between the active layer 55 and the first conductivity type semiconductor region 53 and the active layer 55 and the second conductivity type semiconductor layer 57.

[0079] In a second example of the semiconductor light-emitting device 51:

the first conductivity type semiconductor region 53: n-type AlGaAs semiconductor and/or GaAs semiconductor;

the active layer 55: un-GaInNAs semiconductor, un-GaNAs semiconductor, un-GaNAsSb semiconductor, un-GaNAsP semiconductor, un-GaNAsSbP semiconductor, un-GaInNAsSb semiconductor, un-GaInNAsP semiconductor, and/or un-GaInNAsSbP semiconductor;

the second conductivity type semiconductor layer 57: p-type AlGaAs semiconductor and/or p-type GaAs semiconductor;

the second conductivity type semiconductor layer 65: p-type AlGaAs semiconductor and/or p-type GaAs semiconductor;

the first current block semiconductor layer 59a:

p-type AlGaInP semiconductor, p-type AlGaAs semiconductor,
p-type GaAs semiconductor, and/or p-type GaInP
semiconductor;

the second current block semiconductor layer 59b:
5 n-type AlGaInP semiconductor, n-type GaInP semiconductor,
n-type AlGaAs semiconductor, and/or n-type GaAs
semiconductor;

the substrate 61: heavily-doped n-type GaAs
substrate; and

10 the contact layer 67: p-type GaAs semiconductor. In
the semiconductor optical device 51, the first conductivity
type semiconductor region 53 and the second conductivity
type semiconductor layer 57 may be made of an $\text{Al}_x\text{Ga}_{1-x}\text{As}$
semiconductor, whereas each of the first and second current
15 block layers 59a and 59b may be made of an $\text{Al}_x\text{Ga}_{1-x}\text{As}$
semiconductor and/or an $(\text{Al}_x\text{Ga}_{1-x})_y\text{In}_{1-y}\text{P}$ semiconductor that
lattice-matches to GaAs semiconductor. In these
semiconductor crystals, composition "X" has a value within
the range of zero or greater but not greater than 1. Using
20 these semiconductor materials can improve the carrier
confinement at the following interfaces: the active layer
55 and the current block semiconductor regions 59; and the
active layer 55 and the first conductivity type
semiconductor region 53; the active layer 55 and the second
25 conductivity type semiconductor layer 57.

[0080] Therefore, the carrier confinement in

transverse horizontal and longitudinal vertical directions is enhanced in the semiconductor light-emitting device 51, whereby the semiconductor light-emitting device 51 is provided with a lower threshold current, a higher slope efficiency, and an improved temperature characteristic as compared with InP/GaInAsP semiconductor laser devices.

[0081] In the semiconductor optical device 51 made of the above-mentioned semiconductor materials, the active layer 55 is provided so as to generate light having a wavelength of 0.9 micrometers or longer.

[0082] InP semiconductor has band the gap, ΔE_{InP} , and the cladding layers have band gap, ΔE_0 , shown in Fig. 7(b). As can be seen from Fig. 7(b), the band gap, ΔE_0 , is greater than the band gap, ΔE_{InP} . That is, the band gap difference between the active layer (made of one of GaInNAs, GaNAs, GaNAsSb, GaNAsP, GaNAsSbP, GaInNAsSb, GaInNAsP, and GaInNAsSbP semiconductors) and the cladding layer (p-type AlGaInP, n-type AlGaInP, p-type AlGaAs, or n-type AlGaAs semiconductor) can be made greater than the band gap difference between InP semiconductor (having a band gap energy of 2.16×10^{-19} joules (1.35 eV)) and GaInAsP semiconductor. This explanation similarly applies to the active layer 55 and the current block semiconductor region 59 shown in Fig. 7(d).

[0083] Fig. 8(a) is a sectional view showing a modified

example of the semiconductor optical device in accordance with the present embodiment. Fig. 8(b) is a diagram showing the band gap taken along the line IX-IX of Fig. 8(a). Fig. 8(c) is a diagram showing the refractive index taken along the line IX-IX of Fig. 8(a). The semiconductor optical device 51a may further comprise a first SCH layer 75 and a second SCH layer 77. The first SCH layer 75 is provided between the first conductivity type semiconductor region 53(a) and the active layer 55. The second SCH layer 77 is provided between the active layer 55 and the second conductivity type semiconductor layer 57. The first and second SCH layers 75 and 77 are provided between the current block regions 59. The first conductivity type semiconductor region 53, the active layer 55, the second conductivity type semiconductor layer 57, and the first and second SCH layers 75, 77 constitute a semiconductor ridge 63a.

[0084] The first SCH layer 75 exhibits a photoluminescence wavelength value between that of the active layer 55 and that of the first conductivity type semiconductor region 53. The second SCH layer 77 exhibits a photoluminescence wavelength value between that of the active layer 55 and that of the second conductivity type semiconductor layer 57. Carriers are injected into the active layer 5 from the first portion 53(a) of the first conductivity type semiconductor region 53(a) and the second

conductivity type semiconductor layer 57 by way of the first and second SCH layers 75 and 77. In the semiconductor optical device 51a, as shown in Fig. 8(b), the first and second SCH layers 75 and 77 functions to confine the injected carriers into the active layer 55.

[0085] The first SCH layer 75 exhibits a refractive index value between that of the active layer 55 and that of the first conductivity type semiconductor region 53. The second SCH layer 77 exhibits a refractive index value between that of the active layer 55 and that of the second conductivity type semiconductor layer 57. As shown in Fig. 8(c), the first semiconductor region 53 and the second conductivity type semiconductor layer 57 function to confine light generated in the active layer 55 into the active layer 55 and the first and second SCH layers 75 and 77.

[0086] The first and second SCH semiconductor layers 75 and 77 make it possible to confine current and light separately. These SCH layers enhance the confinement of light into the active layer 55, thereby improving oscillation characteristics, such as a reduction in the threshold current, and temperature characteristic of the semiconductor optical device.

[0087] The first and second SCH layers 75 and 77 may be made of an $\text{Al}_x\text{Ga}_{1-x}\text{As}$ semiconductor ($0 \leq x \leq 1$) or a $\text{Ga}_x\text{In}_{1-x}\text{As}_y\text{P}_{1-y}$ semiconductor (about $0.5 \leq x \leq 1$, $0 \leq y \leq 1$)

that lattice-matches to GaAs semiconductor. In the first and second examples of the semiconductor light-emitting device 51a:

the SCH semiconductor layers 75 and 77: $\text{un-Al}_x\text{Ga}_{1-x}\text{As}$ ($0 \leq X \leq 1$), un-GaAs , and/or a $\text{Ga}_x\text{In}_{1-x}\text{As}_y\text{P}_{1-y}$ semiconductor (about $0.5 \leq X \leq 1$, $0 \leq Y \leq 1$) lattice-matching to GaAs semiconductor. In a preferred example, GaInAsP semiconductor is provided so as to lattice-match to GaAs. According to these materials, the refractive indices of the first and second SCH semiconductor layers 75 and 77 are between the refractive indices of the first conductivity type semiconductor region 53(a) and second conductivity type semiconductor layer 57 and the refractive index of the active layer 55, and the photoluminescence wavelengths of the first and second SCH semiconductor layers 75 and 77 are between photoluminescence wavelengths of the first conductivity type semiconductor region 53(a) and second conductivity type semiconductor layer 57 and the photoluminescence wavelength of the active layer 55. Accordingly, the light and carriers can be confined into the active layer 55.

[0088] Fig. 9(a) is a sectional view showing a modified example of the semiconductor optical device in accordance with the present embodiment. Fig. 9(b) is a diagram showing the band gap taken along the line X-X of Fig. 9(a). Fig. 9(c) is a diagram showing the band gap of another

semiconductor optical device taken along a line corresponding to the line X-X of Fig. 9(a). The semiconductor optical device 51b may further comprise an additional semiconductor layer 79 including a III-V compound semiconductor. In the semiconductor optical device 51b, the additional semiconductor layer 79 is provided between the second conductivity type semiconductor layer 57 and the active layer 55. The III-V compound semiconductor of the additional semiconductor layer 79 exhibits a photoluminescence wavelength value between that of the active layer 55 and that of the second conductivity type semiconductor layer 57. The active layer 55, the second conductivity type semiconductor layer 57, and the additional semiconductor layer 79 constitute a semiconductor ridge 63b.

[0089] In Fig. 9(a), the semiconductor light-emitting device 51b has the additional semiconductor layer 79 provided between the second conductivity type semiconductor layer 57 and the active layer 55, but it may be provided between the first conductivity type semiconductor region 53(a) and the active layer 55 as shown in Fig. 9(c). If the additional semiconductor layer 79 is provided between the first conductivity type semiconductor region 53(a) and the active layer 55, the III-V compound semiconductor of the additional semiconductor layer 79 exhibits a photoluminescence wavelength value between that

of the first conductivity type semiconductor region 53(a) and that of the active layer 55. A pair of additional semiconductor layers may be provided on both sides of the active layer 55 as well. That is, the additional semiconductor layer 79 may be provided in at least one of following interfaces: the first conductivity type semiconductor region 53(a) and the active layer 55; the second conductivity type semiconductor layer 57 and the active layer 55.

[0090] According to this relationship of photoluminescence wavelengths, the additional semiconductor layer 79 lowers spikes and notches at the following interfaces: between the active layer 55 and the first conductivity type semiconductor region 53; between the active layer 55 and the second conductivity type semiconductor layer 57. Therefore, the heterobarriers at those interfaces are alleviated.

[0091] In the first and second examples of the semiconductor light-emitting device 51b, the semiconductor layer 79: p-type AlGaAs, p-type AlGaInP, p-type GaInP, and/or p-type GaInAsP semiconductor.

[0092] Fig. 10 is a sectional view showing a modified example of the semiconductor optical device in accordance with the present embodiment. The semiconductor optical device 51c including SCH layers 75 and 77 may further include an additional semiconductor layer 81 having a III-V

compound semiconductor. The additional semiconductor layer 81 is provided in at least one of following interfaces: the first conductivity type semiconductor region 53 and the first SCH layer 75; the second conductivity type semiconductor layer 57 and the second SCH layer 77. If the additional semiconductor layer 81 is provided between the second conductivity type semiconductor layer 57 and the second SCH layer 77 as in the semiconductor optical device 51c shown in Fig. 10A, the III-V compound semiconductor of the additional semiconductor layer 81 exhibits a photoluminescence wavelength value between that of the second SCH layer 77 and that of the second conductivity type semiconductor layer 57. If the additional semiconductor layer 81 is provided between the first conductivity type semiconductor region 53 and the first SCH layer 75, the III-V compound semiconductor of the additional semiconductor layer 81 has a photoluminescence wavelength value between that of the first SCH layer 75 and that of the first conductivity type semiconductor region 53. The active layer 55, the second conductivity type semiconductor layer 57, the first and second SCH layers 75 and 77, and the additional semiconductor layer 81 constitute a semiconductor ridge 63c. The semiconductor layer 81 of the semiconductor light-emitting device 51c can be made of the same material as the semiconductor layer 79.

[0093] According to this photoluminescence wavelength relationship, the additional semiconductor layer 81 lowers spikes and notches at the following heterojunction interfaces: the SCH layer 75 and the first conductivity type semiconductor region 53; the SCH layer 77 and the second conductivity type semiconductor layer 57. The heterobarriers at these interfaces are thereby alleviated.

[0094] Although the first and second embodiments of the present invention are described with reference to a number of modified examples in the foregoing, the embodiments are not limited thereto. In the semiconductor optical device in accordance with a further modified example, each of the first and second current block semiconductor layers is made of a III-V compound semiconductor including no aluminum (Al) as a III group element. If the first and second current block semiconductor layers are made of semiconductor materials including Al atoms, these Al atoms may be gradually oxidized with time around the interface between an active layer and a current block semiconductor region, thereby increasing the number of nonluminous centers. If the first and second current block semiconductor layers do not contain Al as a III group member, there is no occurrence of Al oxidization deteriorating the characteristics and reliability of the semiconductor light-emitting device. A GaInP

semiconductor can be presented as an example of III-V compound semiconductor that includes no Al as a III group member. In a preferred example, the GaInP semiconductor lattice-matches to GaAs semiconductor.

5 [0095] If a III-V semiconductor material including Al is used as material for a current block semiconductor region, Al oxidization may occur in the step of burying the semiconductor ridge including an active layer at the following interfaces: the current block semiconductor region and the semiconductor ridge; and/or the current block semiconductor region and a first conductivity type semiconductor region. Thus, the current block semiconductor region with a favorable crystal quality cannot be provided due to the Al oxidization. For example, 10 GaInP semiconductors do not include Al, and thus do not incur such a problem coming from the Al oxidization. The band gap of GaInP semiconductors is greater than that of III-V semiconductors including nitrogen (N). A current block semiconductor region including a GaInP semiconductor favorably confines carriers into an active layer. Further, 15 the refractive index of GaInP semiconductors is lower than that of III-V semiconductors including nitrogen (N). A current block semiconductor region including a GaInP semiconductor favorably confines light in horizontal transverse directions into an active layer. 20 25

[0096] While the current block semiconductor region

is made of a GaInP semiconductor, the active layer may be made of a semiconductor including no Aluminum (Al) as a III group member and the first conductivity type semiconductor region and second conductivity type semiconductor layer may be made of a GaInP semiconductor. In this semiconductor light-generating device, the emission characteristic of the active layer may be deteriorated due to Al oxidization and the crystal quality of the current block semiconductor region may be degraded due to Al oxidization in a burying step. If the second conductivity type semiconductor layer and the current block semiconductor region are made of materials that does not contain Aluminum (Al) as a III group member, an additional second conductivity type semiconductor layer can be grown on the current block semiconductor region and second conductivity type semiconductor layer without the degradation of the crystal quality due to Al oxidization. Thus, the buried semiconductor light-emitting device has higher performances and higher reliability.

[0097] In the semiconductor light-emitting device having a light-generating region including the active layer made of III-V semiconductor including no aluminum as a III group member and a heterobarrier alleviating layer made of a GaInAsP semiconductor, the first conductivity type semiconductor region, the second conductivity type semiconductor layer, and the current block semiconductor

region may be made of GaInP semiconductor. In a preferred example, the GaInP semiconductor lattice-matching to GaAs semiconductor is used. In this configuration, semiconductor layers constituting the semiconductor optical device are made of semiconductor without Al acting as a III group member, so that there is no occurrence of degradation of the reliability and emission characteristics of the semiconductor optical device due to the Al oxidization.

[0098] In the semiconductor optical device having an active layer made of III-V semiconductor including no Al as a III group member and a light-emitting region provided with an SCH layer, for example, the SCH layer may be made of at least one of GaAs and GaInAsP semiconductors, whereas the first conductivity type semiconductor region, second conductivity type semiconductor layer and the current block semiconductor region may be made of a GaInP semiconductor. In a preferred example, the GaInP and GaInAsP semiconductors lattice-matching to GaAs semiconductor can be used. Since the semiconductor layers constituting the semiconductor optical device do not include Al, the reliability and emission characteristics of the semiconductor optical device is not degraded due to the Al oxidization.

[0099] In the semiconductor optical device having a light-emitting region including SCH layers and an active

layer that are made of III-V semiconductor without Al as a III group member, for example, the SCH layer may be made of at least one of GaAs and GaInAsP semiconductors. Further, the heterobarrier alleviating layer may be made of a GaInAsP semiconductor. Furthermore, the first conductivity type semiconductor region, second conductivity type semiconductor layer and the current block semiconductor region may be made of a GaInP semiconductor. In a preferred example, the GaInP and GaInAsP semiconductors lattice-matching to GaAs semiconductor can be used. Since the semiconductor layers constituting the semiconductor optical device are made of semiconductors without Al acting as a III group member, the reliability and emission characteristics of the semiconductor optical device is not degraded because of the Al oxidization.

[0100] In the foregoing, the semiconductor optical device including a semiconductor light-emitting element such as laser diode is described in the first and second embodiments, but the embodiments of the semiconductor optical device is not limited to the semiconductor light-emitting device. The semiconductor optical device may include any of a semiconductor laser diode, a semiconductor optical amplifier, and an electroabsorption modulator. Furthermore, the semiconductor optical device may be an optical integrated device composed of a plurality of components, such as a semiconductor laser diode,

semiconductor optical amplifier, and electroabsorption modulator.

[0101] The structures disclosed in the embodiments make it possible to enhance the confinement of carriers in any of the semiconductor laser, semiconductor optical amplifier, electroabsorption modulator, and the optical integrated device by use of semiconductor material having a band gap higher than that of InP semiconductor, thereby improving their temperature characteristics as compared with InGaAsP/InP semiconductor optical devices.

[0102] Preferably, III-V compound semiconductor in the first and second embodiments includes at least gallium element (Ga) as a III group member, and at least arsenic element (As) and nitrogen element (N) as V group members. The lattice constant of this material can be made identical or close to that of a GaAs semiconductor, so that the active layer can be grown on the GaAs semiconductor.

[0103] In the semiconductor optical devices 1 and 51, the band gap energy difference in heterojunctions made of InP/GaInAs semiconductors is smaller than the heterojunction band gap energy differences in the following combinations: the active layer and the first conductivity type semiconductor region; the active layer and the second conductivity type semiconductor layer; the active layer and the first; and the active layer and the second current block layers. These combinations improve the confinement of

carriers into the active layer.

[0104] In the semiconductor optical devices in accordance with the present embodiments, III-V compound semiconductor including nitrogen (N) can be used in the active layer. For example, one candidate of the III-V compound semiconductor including nitrogen (N) is a III-V compound semiconductor including at least nitrogen (N), gallium (Ga) and arsenic (As). This III-V semiconductor has a lattice constant identical or close to that of GaAs. Therefore, the III-V compound semiconductor crystal can favorably be grown on a GaAs semiconductor surface. The III-V compound semiconductor including at least nitrogen (N), gallium (Ga), and arsenic (As) has a band gap corresponding to a wavelength band of 0.9 micrometers or longer. Hence, using this III-V compound semiconductor in the active layer can realize semiconductor light-emitting devices that generate light having a wavelength of 0.9 micrometers or longer, e.g., a 1.3-micrometer band optical communication light source or 1.55-micrometer band optical communication light source.

[0105] GaInAs and GaInAsP semiconductor crystals can be grown on a GaAs substrate to form an active layer of an optical device. But, the difference between the lattice constant of these crystals and the lattice constant of the GaAs substrate becomes too large in an oscillation wavelength of 1 micrometer or longer, resulting in

excessive strains in the crystal of the active layer. Due to the excessive strains, the quality of the crystal is likely to deteriorate. Therefore, the optical semiconductor device can attain favorable oscillation characteristics and reliability. By contrast, a III-V compound semiconductor including at least nitrogen, gallium, and arsenic has a lattice constant identical or close to that of the GaAs semiconductor, and thus is free of excessive crystal strains, so that better oscillation characteristics and reliability can be realized in the optical semiconductor device without excessive strains even in the light-emitting devices that generate light of an oscillation wavelength of 1 micrometer or longer.

[0106] Examples of the III-V compound semiconductor including at least nitrogen, gallium, and arsenic are GaNAs and GaInNAs semiconductors. These semiconductors are new materials that have recently been developed. Their compositions of constituent elements (Ga, In, N, As) can be adjusted to obtain the following semiconductor material: semiconductor material lattice-matching to GaAs semiconductor; semiconductor material having a lattice constant close to that of GaAs semiconductor (with a lattice mismatch within ± 2 percent); and semiconductor material for generating light having a wavelength of 0.9 micrometers or longer. Therefore, a long wavelength semiconductor light-emitting device can be realized on a GaAs

semiconductor layer or GaAs substrate.

[0107] GaNAs semiconductors, GaInNAs semiconductors, and the like may further be doped with antimony (Sb) and/or phosphorus (P) as a V group member. Antimony element, acting as a so-called surfactant, can restrain the three-dimensional growth of GaInNAs semiconductors, thereby being effective in improving the crystal quality of GaNAs and GaInNAs semiconductors. Phosphorus element is effective in reducing local crystal strains within GaNAs and GaInNAs semiconductors, and in increasing the number of nitrogen atoms taken into crystals as a V group element. GaInNAsP semiconductors are advantageous in that there is no difficulty in growing the crystals due to the immiscibility gap in the phase diagram.

[0108] The semiconductor light-emitting devices in accordance with the first and second embodiments may include a cladding layer made of an $\text{Al}_x\text{Ga}_{1-x}\text{As}$ semiconductor ($0 \leq x \leq 1$) and/or an $(\text{Al}_x\text{Ga}_{1-x})_y\text{In}_{1-y}\text{P}$ semiconductor ($0 \leq x \leq 1$) that lattice-matches to GaAs semiconductor. Using these materials can improve the confinement of carriers. Among semiconductor materials in an InP/InGaAsP long-wavelength semiconductor laser device, InP semiconductor exhibits the largest band gap of 2.16×10^{-19} joules (1.35 eV). If a cladding layer of this semiconductor laser device is made of InP semiconductor, the band gap difference between the cladding layer and the active layer

cannot be made large, and thus the carrier confinement cannot be improved.

[0109] The $(\text{Al}_x\text{Ga}_{1-x})_y\text{In}_{1-y}\text{P}$ semiconductor ($0 \leq x \leq 1$) lattice-matching to GaAs semiconductor has a band gap value within the range of 3.06×10^{-19} joules (1.91 eV) or greater but not greater than 3.92×10^{-19} joules (2.45 eV) as the composition X of Al changes. The $\text{Al}_x\text{Ga}_{1-x}\text{As}$ semiconductor ($0 \leq x \leq 1$) has a band gap value within the range of 2.27×10^{-19} joules (1.42 eV) or greater but not greater than 3.19×10^{-19} joules (1.99 eV) as the composition X of Al changes. Accordingly, the band gap difference between the cladding layer and the active layer is made greater than that in InP/GaInAsP semiconductor laser, and the confinement of carriers into the active layer can be improved. Therefore, the temperature characteristic of the semiconductor light-emitting device can be improved.

[0110] An active layer may be made of at least one of the following semiconductor material: GaInNAs; GaNAs; GaNAsSb; GaNAsP; GaNAsSbP; GaInNAsSb; GaInNAsP; and GaInNAsSbP semiconductors, and a cladding layer may be made of an $(\text{Al}_x\text{Ga}_{1-x})_y\text{In}_{1-y}\text{P}$ semiconductor ($0 \leq x \leq 1$) or an $\text{Al}_x\text{Ga}_{1-x}\text{As}$ semiconductor ($0 \leq x \leq 1$). If a semiconductor optical device generating light of the oscillation wavelength of 1.3 micrometer band has an active layer of a band gap, about 1.53×10^{-19} joules (0.954 eV), then the band gap difference realized by use of the AlGaInP

semiconductor is 1.53×10^{-19} joules (0.956 eV) at the minimum and 2.4×10^{-19} joules (1.496 eV) at the maximum, and the band gap difference realized by use of the AlGaAs semiconductor is 0.75×10^{-19} joules (0.466 eV) at the minimum and 1.66×10^{-19} joules (1.036 eV) at the maximum.

[0111] When a semiconductor optical device generating light of the oscillation wavelength of 1.55 micrometer band, on the other hand, has the active layer of a band gap, about 1.28×10^{-19} joules (0.8 eV), then the band gap difference realized by use of the AlGaInP semiconductor is 1.78×10^{-19} joules (1.1 eV) at the minimum and 2.64×10^{-19} joules (1.65 eV) at the maximum, and the band gap difference realized by use of the AlGaAs semiconductor is 0.99×10^{-19} joules (0.62 eV) at the minimum and 1.91×10^{-19} joules (1.19 eV) at the maximum.

[0112] As the Aluminum composition increases in $\text{Al}_x\text{Ga}_{1-x}\text{As}$ semiconductor ($0 \leq X \leq 1$) and $(\text{Al}_x\text{Ga}_{1-x})_y\text{In}_{1-y}\text{P}$ semiconductor ($0 \leq X \leq 1$) that lattice-matches to GaAs semiconductor, the band gap increases and the refractive index decreases. If the cladding layer and the current block layer are made of semiconductor material with a relatively smaller aluminum composition and semiconductor material with a relatively larger aluminum composition, respectively, the cladding layer has a refractive index higher than the refractive indices of the current block layers. Therefore, the effective refractive index in a

semiconductor stripe located between the current block layers can be made higher than that of the current block layers. This structure realizes a refractive index guiding in the lateral transverse direction, thereby realizing a low threshold in the semiconductor laser device.

The refractive index guiding structure stabilizes the confinement of light in the lateral transverse direction, and thus enables the semiconductor laser device to achieve a single-mode oscillation in a fundamental mode. The semiconductor laser device exhibits a single-peak far field pattern (FFP), so that optical coupling with optical fiber and the semiconductor laser device is enhanced. Therefore, semiconductor laser devices of the embodiments can improve semiconductor laser characteristics over anti refractive index guiding type InP buried ridge type laser devices.

[0113] If the current block semiconductor region is made of $(\text{Al}_x\text{Ga}_{1-x})_y\text{In}_{1-y}\text{P}$ semiconductor ($0 \leq x \leq 1$) and/or $\text{Al}_x\text{Ga}_{1-x}\text{As}$ semiconductor ($0 \leq x \leq 1$) which has a band gap greater than that of InP semiconductor, the heterobarrier between the active layer and the current block semiconductor region can be made greater, and thus the confinement of carriers into the active layer is further enhanced. As compared with InP/GaInAsP buried heterostructure semiconductor laser devices, the semiconductor laser device according to the present embodiments has the following advantages: the threshold

current is lowered; the slope efficiency is increased; and the temperature characteristic is further improved.

[0114] In the semiconductor optical devices 1 and 51, the active layer may have a quantum well structure. For example, the quantum well structure may be one of SQW and MQW structures, but the structure of the active layer is not limited thereto. For example, a well layer can be made of the same material as that of the active layer, whereas a barrier layer can be made of the same material as that of the SCH layers, such as AlGaAs, GaAs, or GaInAsP semiconductor.

[0115] In the semiconductor light-emitting devices according to the first and second embodiments, the SCH layers are made of material having a refractive index between that of the active layer and that of the cladding layer. In order to achieve favorably confinement of carriers into the active layer, the SCH layers are made of material exhibiting a photoluminescence wavelength between that of the active layer and that of the cladding layer. In order to realize the above semiconductor light-emitting devices, the following combination can be used: the cladding layer made of $(\text{Al}_x\text{Ga}_{1-x})_y\text{In}_{1-y}\text{P}$ semiconductor ($0 \leq x \leq 1$) or $\text{Al}_x\text{Ga}_{1-x}\text{As}$ semiconductor ($0 \leq x \leq 1$); and the SCH layers made of GaInAsP semiconductor that lattice-matches to GaAs semiconductor and/or $\text{Al}_x\text{Ga}_{1-x}\text{As}$ semiconductor ($0 \leq x \leq 1$). Using the SCH layers enhances the confinement of

light into the active layer, thus improving the oscillation characteristics of the semiconductor light-emitting devices, such as a low threshold current and an excellent temperature characteristic. In particular, the SCH layers works effectively if the active layer has a quantum well constituted by very thin films.

[0116] The semiconductor light-emitting devices in accordance with the first and second embodiments may have a heterobarrier alleviating layer provided between the cladding layer and the SCH layer or active layer. A heterobarrier is produced at the heterostructure interface between the following layers: the cladding layer and active layer; and the SCH layer and cladding layer. The height of the heterobarrier depends on the band gap difference between the semiconductor materials thereof. This heterobarrier is known as a spike or notch, and has a wedge shape in an energy band diagram. This heterobarrier works as a barrier, ΔE_c , for electrons in a conduction band and creates electric resistance thereto, and works as a barrier, ΔE_v , for holes in a valence band and creates electric resistance thereto. The combination of an $(Al_xGa_{1-x})_yIn_{1-y}P$ cladding layer and a GaAs SCH layer forms a p-n junction having a relatively large heterobarrier in the valence band, for example. This heterobarrier increase the electric resistance within the semiconductor light-emitting device, thereby generating greater heat in the semiconductor

light-emitting device. Further, this heterobarrier degrades the efficiency of carrier injection into the active layer. In particular, majority carriers in p-type semiconductors are holes, which exhibit low mobility due to their large effective mass, thereby lowering the efficiency of hole injection into the active layer. Hence, the large heterobarrier may be one of causes that degrade the long-term reliability and high output characteristic of the semiconductor light-emitting device, and so on. Lowering the heterobarrier is important to produce a semiconductor light-emitting device with the improved device characteristics and long-term reliability. The heterobarrier alleviating layer is useful for lowering the heterobarrier.

[0117] $(\text{Al}_x\text{Ga}_{1-x})_y\text{In}_{1-y}\text{P}$ semiconductor ($0 \leq x \leq 1$); $\text{Al}_x\text{Ga}_{1-x}\text{As}$ semiconductor ($0 \leq x \leq 1$); and $\text{Ga}_x\text{In}_{1-x}\text{As}_y\text{P}_{1-y}$ semiconductor can be used as the heterobarrier alleviating layer, for example in the semiconductor light-emitting device having a cladding layer made of $(\text{Al}_x\text{Ga}_{1-x})_y\text{In}_{1-y}\text{P}$ semiconductor ($0 \leq x \leq 1$) and/or $\text{Al}_x\text{Ga}_{1-x}\text{As}$ semiconductor ($0 \leq x \leq 1$), and an SCH layer made of $\text{Al}_x\text{Ga}_{1-x}\text{As}$ semiconductor ($0 \leq x \leq 1$) and/or $\text{Ga}_x\text{In}_{1-x}\text{As}_y\text{P}_{1-y}$ semiconductor (about $0.5 \leq x \leq 1$, $0 \leq y \leq 1$) lattice-matching to GaAs semiconductor.

[0118] The material of the heterobarrier alleviating layer may have a composition attaining a lattice mismatch in a range of -2 percent or more but not greater than +2

percent with respect to the lattice constant of a semiconductor substrate. In general, the heterobarrier alleviating layer has a thickness smaller than its critical film thickness. The film thickness of the heterobarrier alleviating layer is, for example, in a range of 5 nanometers or more but not greater than 10 nanometers, preferably 5 nanometers. If the lattice mismatch falls within this range, crystal defects are hard to occur. The acceptable range of lattice mismatch is widened, and thus the range of the composition of semiconductor material is expanded. If the cladding layer is made of $\text{Al}_x\text{Ga}_{1-x}\text{As}$ semiconductor ($0 \leq X \leq 1$) or $(\text{Al}_x\text{Ga}_{1-x})_Y\text{In}_{1-Y}\text{P}$ semiconductor ($0 \leq X \leq 1$) that lattice-matches to GaAs semiconductor and the SCH semiconductor layer is made of $\text{Al}_x\text{Ga}_{1-x}\text{As}$ semiconductor ($0 \leq X \leq 1$) or $\text{Ga}_x\text{In}_{1-x}\text{As}_Y\text{P}_{1-Y}$ semiconductor (about $0.5 \leq X \leq 1$, $0 \leq Y \leq 1$) that lattice-matches to GaAs semiconductor, $(\text{Al}_x\text{Ga}_{1-x})_Y\text{In}_{1-Y}\text{P}$ semiconductor and/or $\text{Ga}_x\text{In}_{1-x}\text{As}_Y\text{P}_{1-Y}$ semiconductor can be used to form a strained heterobarrier alleviating layer, for example.

[0119] In the semiconductor light-emitting device in accordance with the second embodiment, a semiconductor film of the first conductivity type is formed on a substrate. Semiconductor films constituting a light-emitting region are then formed on the semiconductor film of the first conductivity type, and thereafter a semiconductor film of the second conductivity type is formed on the semiconductor

film. After these semiconductor films are formed, the semiconductor films are etched selectively against the semiconductor film of the first conductivity type. This selective etching is performed using a predetermined etchant. This etchant can etch the semiconductor film constituting the light-emitting region and the second conductivity type semiconductor film, but cannot etch the first conductivity type semiconductor region, thereby forming a semiconductor ridge.

[0120] In InP/GaInAsP long wavelength laser devices, Br methanol is typically used for etching to form a semiconductor ridge. Since Br methanol has no etching selectivity for InP semiconductor of the lower cladding layer (first conductivity type semiconductor region), the lower cladding layer is also etched in the etching step of forming the ridge. Due to volatility of Br methanol, its etching rate is changed with time. Slight fluctuations in temperature, concentration, and mixing ratio of the etching solution cause the etching rate to vary during the etching step. Consequently, etchant having a predetermined etching rate cannot be prepared for each etching step. In addition, in stirring the etching solution in which a wafer is soaked, the etching rates are varied on the surface of the wafer due to the difference in its stirring rate between an outer part and its center on the surface of the wafer. That is, the etching rate is fluctuated depending on the

number of uses of the etching solution, and the depths of the ridges are varied on the wafer surface. With Br methanol, the amount of the side etching varies nonlinearly as the depth of the ridge is greater. The width of the active layer is fluctuated depending on that of the depth of the ridge, thereby generating nonlinear variations in the width of the active layer. The nonlinear variations in the width of the active layer deteriorate the reproducibility and uniformity of laser characteristics.

[0121] However, in the semiconductor optical device in accordance with the second embodiment, a predetermined etching solution (e.g., phosphoric acid etchant) may be used for selectively etching the semiconductor films of the SCH layer and the active layer against the lower cladding layer in the semiconductor optical device constituted by the following: the cladding layer made of $(\text{Al}_x\text{Ga}_{1-x})_y\text{In}_{1-y}\text{P}$ semiconductor ($0 \leq X \leq 1$) lattice-matching to GaAs semiconductor; the SCH semiconductor layer made of $\text{Al}_x\text{Ga}_{1-x}\text{As}$ semiconductor ($0 \leq X \leq 1$) or $\text{Ga}_x\text{In}_{1-x}\text{As}_y\text{P}_{1-y}$ semiconductor (about $0.5 \leq X \leq 1$, $0 \leq Y \leq 1$) that lattice-matches to GaAs semiconductor; and the active layer made of III-V semiconductor material including nitrogen (e.g., GaInNAs, GaNAs, GaNAsSb, GaNAsP, GaNAsSbP, GaInNAsSb, GaInNAsP, and GaInNAsSbP semiconductors), for example. The semiconductor optical device having a buried heterostructure is obtained. In the semiconductor

light-emitting device in accordance with the second embodiment, the semiconductor layer provided below the active layer or SCH layer functions as an etch stop layer. Therefore, the ridge depth exhibits favorable reproducibility and uniformity on the wafer. Consequently, the reproducibility and the uniformity on the wafer are improved in the width of the active layer. The semiconductor light-emitting device may further include a heterobarrier alleviating layer made of $(\text{Al}_x\text{Ga}_{1-x})_y\text{In}_{1-y}\text{P}$ semiconductor ($0 \leq x \leq 1$), $\text{Al}_x\text{Ga}_{1-x}\text{As}$ semiconductor ($0 \leq x \leq 1$), and/or $\text{Ga}_x\text{In}_{1-x}\text{As}_y\text{P}_{1-y}$ semiconductor, in order to reduce the internal resistance.

[0122] As explained in the foregoing, the semiconductor light-emitting devices in accordance with the first and second embodiments can provide some technical contributions which have not been overcome by InGaAsP/InP semiconductor optical devices. For example, the semiconductor light-emitting devices in accordance with the first and second embodiments can solve problems in terms of high temperature characteristics which have occurred in InGaAsP/InP semiconductor laser devices. Hence, the semiconductor light-emitting devices in accordance with the first and second embodiments have advantageous temperature characteristics superior to InGaAsP/InP semiconductor optical devices.

[0123] Having described and illustrated the principle

of the invention in a preferred embodiment thereof, it is appreciated by those having skill in the art that the invention can be modified in arrangement and detail without departing from such principles. For example, the semiconductor optical device encompasses not only semiconductor light-emitting devices, but also semiconductor laser devices, semiconductor optical amplifier devices, semiconductor optical integrated devices including EA modulators, and the like, as well as integrated devices integrating these devices. Details of structures of these devices can be modified as necessary. We therefore claim all modifications and variations coming within the spirit and scope of the following claims.

[0124]

[Effect of the Invention]

As explained as above, the present invention provides a semiconductor optical device having a temperature characteristic superior to those of InGaAsP/InP semiconductor optical devices.

[BRIEF DESCRIPTION OF THE DRAWINGS]

[Fig. 1]

Fig. 1 is a perspective view showing the semiconductor light-emitting device in accordance with the first embodiment.

[Fig. 2]

Fig. 2(a) is a sectional view taken along the line

I-I shown in Fig. 1. Fig. 2(b) is a diagram showing the band gap taken along the line II-II of Fig. 2(a). Fig. 2(c) is a diagram showing the refractive index taken along the line II-II of Fig. 2(a). Fig. 2(d) is a diagram showing the band gap taken along the line III-III of Fig. 2(a). Fig. 2(e) is a diagram showing the refractive index taken along the line III-III of Fig. 2(a).

[Fig. 3]

Fig. 3(a) is a sectional view showing a modified example of the semiconductor optical device in accordance with the present embodiment. Fig. 3(b) is a diagram showing the band gap taken along the line IV-IV of Fig. 3(a). Fig. 3(c) is a diagram showing the refractive index taken along the line IV-IV of Fig. 3(a).

[Fig. 4]

Fig. 4(a) is a sectional view showing a modified example of the semiconductor optical device in accordance with the present embodiment. Fig. 4(b) is a diagram showing the band gap taken along the line V-V of Fig. 4(a). Fig. 4(c) is a diagram, showing the band gap of another semiconductor optical device taken along a line corresponding to the line V-V of Fig. 4(a).

[Fig. 5]

Fig. 5 is a sectional view showing a modified example of the semiconductor optical device in accordance with the present invention.

[Fig. 6]

Fig. 6 is a perspective view showing the semiconductor light-emitting device in accordance with the second embodiment.

5 [Fig. 7]

Fig. 7(a) is a sectional view taken along the line VI-VI shown in Fig. 6. Fig. 7(b) is a diagram showing the band gap taken along the line VII-VII of Fig. 7(a). Fig. 7(c) is a diagram showing the refractive index taken along the line VII-VII of Fig. 7(a). Fig. 7(d) is a diagram showing the band gap taken along the line VIII-VIII of Fig. 7(a). Fig. 7(e) is a diagram showing the refractive index taken along the line VIII-VIII of Fig. 7(a).

[Fig. 8]

15 Fig. 8(a) is a sectional view showing a modified example of the semiconductor optical device in accordance with the present embodiment. Fig. 8(b) is a diagram showing the band gap taken along the line IX-IX of Fig. 8(a). Fig. 8(c) is a diagram, showing the refractive index of the semiconductor optical device taken along a line corresponding to the line IX-IX of Fig. 8(a).

[Fig. 9]

25 Fig. 9(a) is a sectional view showing a modified example of the semiconductor optical device in accordance with the present embodiment. Fig. 9(b) is a diagram showing the band gap taken along the line X-X of Fig. 9(a). Fig.

9(c) is a diagram, showing the band gap of another semiconductor optical device, taken along a line corresponding to the line X-X of Fig. 9(a).

[Fig. 10]

5 Fig. 10 is a sectional view showing a modified example of the semiconductor optical device in accordance with the present embodiment.

【Explanation of Symbols】

1, 1a, 1b, 1c ...semiconductor optical device, 3...first
 10 conductive type semiconductor region, 5...active layer,
 7...second type semiconductor layer, 9...current block
 semiconductor region, 11...substrate, 15...second conductive
 type semiconductor layer, 17...contct layer, 21,
 23...electrode, 25, 27...SCH layer, 29, 31...heterobarrier
 15 alleviating layer, 51, 51a, 51b, 51c ...semiconductor optical
 device, 53...first conductive type semiconductor region,
 55...active layer, 57...second type semiconductor layer,
 59...current block semiconductor region, 61...substrate,
 65...second conductive type semiconductor layer, 67...contct
 20 layer, 71, 73...electrode, 75, 77...SCH layer, 79,
 81...heterobarrier alleviating layer